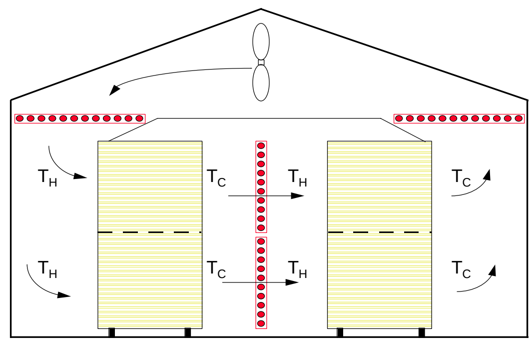
Improved Multi-Zone Kiln Control System



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Introduction:

Figure (1) depicts a typical cross-section of a multi-zoned lumber kiln. This kiln configuration can be extended from 4 zones to 8, 12, 16, etc. Temperature sensors are located for use in determining the temperature drop (Thot ï Tcold) across the loadð usually referred to as TDAL or delta t.

Figure (1) -- Cross-Section of a Multi-Zone Lumber Kiln

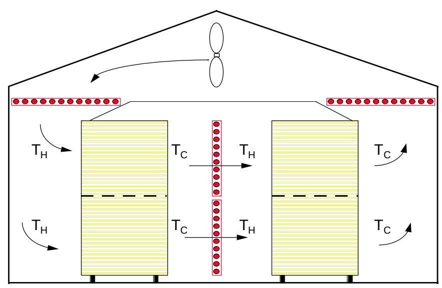
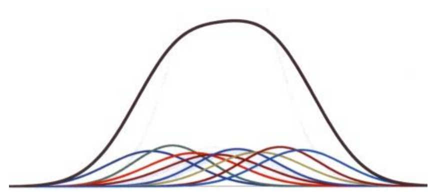


Figure (2) depicts the overall MC distribution of a kiln load of green lumber as consisting of a number of individual zone MC distribution curves distributed along the x-axis, starting with the zone with the lowest mean MC on the extreme left side and continuing rightward to the zone with the maximum mean MC located at the extreme far right side. It is assumed that the individual zone MC distributions are normal; however, this is not required for the control method discussed herein to be successful.

Figure (2) – MC Distribution for Kiln Load of Green Lumber



The Control Problem:

Figure (2) illustrates the difficulty of controlling all zones, each containing a heterogeneous mix of lumber MCs, such that all zones converge into one overall MC distribution curve at the target mean MC; with a MC variation (standard deviation) as low as feasible; while drying the load in the shortest amount of time practicable.

Kiln Drying:

Following warmup, lumber drying involves an initial period of constant-rate drying where sufficient MC is available on the surface of the lumber for a period of time such that the drying rate is essentially constant and drying is considered to be heat transfer controlled. As drying proceeds, water migration to the surface of the lumber slows and the MC fiber saturation point (FSP) is reached at approximately 24 ï 25%, the transition point between constant-rate and falling-rate drying. Below the FSP, drying is said to be directly proportional to the diffusion rate of the water to the lumber surface.

Fortunately, a theoretically based control method has been developed and proven capable of producing further reductions in degrade, drying time, and energy consumptionð especially during the falling-rate period of drying.

Kiln Control Solution:

Modeling a wood veneer dryer was begun off and on by the author in 1976. The Delta T general dryer/MC control model was completed in the late 1970ôs. It applied to batch dryers as well as continuous dryers by relating the product MC to: (1) the temperature drop (æT) of hot air after contacting the lumber in a zone; and (2) the elapsed drying time (ɗ) as shown in equation (1) below:

$$\mathbf{MC = K_3(\Delta T)^s - K_4\theta^r} \qquad \textbf{(1)}$$

This model form was made more convenient for use on continuous dryers or kilns by converting time to speed (S) as shown in equation (2) below:

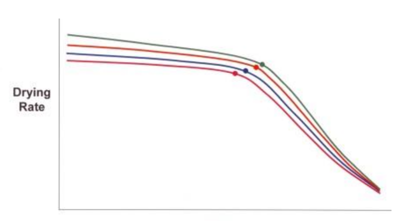
$$\mathbf{MC = K_1(\Delta T)^p - (K_2/S^q)} \qquad \textbf{(2)}$$

This batch model appeared ideally suited for use in comparing zone MCs using the φT parameter; however, it was soon discovered that the use of æT or TDAL(introduced later) was accompanied by errors in MC prediction due to zone-to-zone differences in air mass flow through the lumber stacks. Consequently, use of delta t or TDAL has not been entirely successful for comparing zone-to-zone drying in a lumber kiln.

Fortunately, when the Delta T model is used as the basis for a multi-zone kiln control system, errors in air mass flow are eliminated by using individual zone drying rates. Since drying rate and MC are directly proportional, this allows drying rates to be used for comparing zone-to-zone drying**.** *This solved the main problem associated with traditional lumber kiln control—lack of a suitable parameter for comparing zone-to-zone drying.*

Figure (3) depicts drying rate Vs time (ɗ) curves for each zone of a hypothetical four-zone kiln. The transition point (FSP) between constant and falling-rate drying is determined for each zone and is shown by the various colored dots on figure (3).

Figure (3) – Zone Drying Rates & Fiber Saturation Points



Detection of the FSP allows determination of when and to what extent heat adjustments should be made to each zone to cause the slower drying zones to ñcatch" the faster drying zones.

Application of Drying Rate Method:

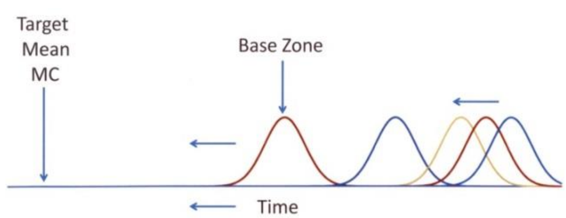
The *exclusive* Delta T Drying Rate Method is applied by continuously calculating drying rates during both the constant and falling-rate drying periods and determining when the FSP for each zone is reached. Knowing when the FSP is reached by each zone allows the proper heat to be applied to achieve convergence of all zones.

Figure (3) shows that while drying in the constant-rate period using the Delta T, zones will be separated according to their initial MC load. The higher the vertical position of the horizontal portion of the zone drying curve, the greater the initial zone MC load; likewise, the lower the vertical position, the lower the initial MC load. This knowledge is used to achieve zone MC convergence during constant-rate drying by using the cold side temperature control.

The point in time each zone reaches the FSP defines its drying rate position relative to the other zones. The first zone to reach the FSP becomes the base against which all remaining zones are controlled. As each successive zone reaches its FSP, heat will be added according to how far in time it lags the baseline zoneǒs drying in order to achieve the kiln control objective of having all zones MCs converge at an overall mean MC with a tighter MC distribution

Figure (4) is a linear plot showing all zones distributed according to their drying rates. It illustrates how, after reaching the FSP, each zone is continuously controlled to converge toward the target MC. The control objective is to cause the MC distribution curves of each zone to be compressed in size and converge toward the overall target MC mean, thus reducing the overall MC distribution curve standard deviation and the overall drying time.

Figure (4) – Continuously Converging Control of Zone rying



This method assures that lumber MC control is optimized because heat flow to each zone is controlled to cause all zone mean MCs to converge ideally at the target mean MC. This continuously converging MC control (CCC) method has been successfully applied to faster drying Southern Pine lumber using high temperature kilns with much success. It should be especially applicable to slower drying softwoods in the Western US and Canada.

Since hardwood quality is highly sensitive to drying rate, this drying rate control method should improve control by measuring and controlling zone drying rates. By gently **c**ausing the individual zones (figure 4) to merge before reaching the conditioning phase, the conditioning time should be significantly shortened, thus reducing the overall time of drying which would result in lower overall drying time and less degrade. This control method would require zoning the kilns.

Drying rates are probably the single-most important variable in lumber drying. Now that the drying rate for each zone can be continuously calculated and displayed and the FSP for each zone detected, more lumber should be placed within the MC limits, less downgraded lumber will be produced, total drying time should be reduced, and more energy can be conserved.

Advantages of Using the Drying Rate Method:

Figure (5) illustrates the advantage of using drying rates for comparing zone drying during the falling-rate drying period. During falling-rate drying, if the Delta T Drying Rate Method is used, lagging zone(s) will converge toward the base curve as shown by the solid line and both degrade and drying time will be reduced. If traditional control methods had been used, the lagging zone would have followed the dashed line which parallels the base line, and there would have been no controlled merging of individual zone MC and less reduction in degrade and drying time.

Figure (5) Delta T Vs Traditional MC Control

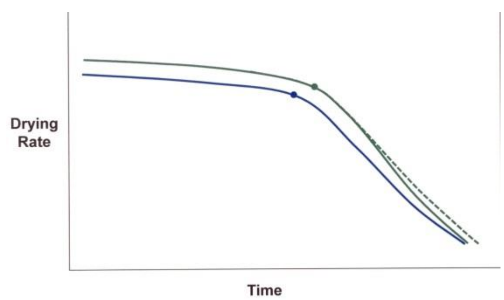
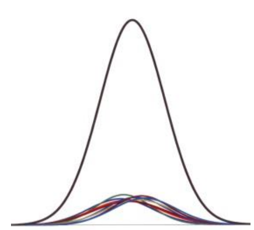


Figure (6) depicts the results of achieving the control objective--reducing degrade, drying time, and energy consumption using the drying rate method of control.

Figure (6) – Typical Final MC Distribution Using the CCC Drying Rate Control Method



Results & Conclusions:

1. Drying rates for all zones of a lumber kiln are continuously calculated and used to control the moisture of each zone of a lumber kiln, rather than a sampling a few boards using capacitance or some other electronic MC sensing method. This produces true zone controlð necessary for effectively controlling a multi-zone kiln.

2. The fiber saturation point (FSP) for each zone is continuously calculated and used to separate the zones according to their MC content at a point in time. This enables the proper amount of heat to be used in controlling individual zones to converge at the target MC with less MC variation.

3. Drier zones are not over-dried and wetter zones are not under-dried.

4. One hundred percent of the kiln lumber is sampled for MC.

5. Overall drying time is reduced (production increase), more lumber placed within limits reduces degrade percent), and energy is conserved.

6. Not only softwood, but hardwoods that are sensitive to drying rates should be improved by using this drying rate control method.

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